Solar Energy Storage - Critical Success Factors for Passive Houses in Ireland

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Abstract

This paper demonstrates that Ireland is potentially the best country in Europe for solar assisted space heating, particularly when seasonal solar energy storage is combined with the exceptionally low space heating demand of Passive Houses. The performance of a real Passive House with a Seasonal Energy Store is examined and presented.

The usefulness of Solar Space Heating is a function of the amount of space heating required and it's pattern. This is more important than absolute solar radiation. Thus a country such as Malta, with high solar radiation and a warm climate, paradoxically benefits from a relatively low annual solar saving. A city such as Dublin, has a high solar saving given that (1) a high proportion of it's heating load falls outside the traditional winter months and (2) the heating load is small due it's maritime climate.

The Critical Success Factors(CSFs) for a real Passive House with an aqueous Seasonal Energy Store are identified and discussed, including climate, solar yield matching with heating demand, optimisation of both the solar energy storage and the heating system, and finally costs. The performance of an installation in Galway, on the west coast of Ireland, is analysed.

Keywords: Thermal Energy Storage, Seasonal Energy Storage, Solar, Passive, Low Energy.

1. Introduction

Scandinavian Homes Ltd., a manufacturer of Passive Homes for the Irish and International market, installed an underground aqueous Seasonal Thermal Energy Store at it's base in Moycullen, Galway, Ireland in June 2009. This seasonal store is used to heat a Passive House of 215m^2 floor area.

This arrangement is made possible by the low space heating demand of 1827kWh (as determined by the Passive House Planning Package - PHPP). The University of Ulster is monitoring and reporting on the performance of the Seasonal Store installation. Key performance figures are recorded every 10 minutes across a range of sensors leading to approximately 10,000 individual data points being recorded daily, using 64 sensors.

An Evacuated Tube Solar collector array, of 10.6m^2 aperture, collects diurnal heat and stores it indirectly in a Domestic Hot Water (DHW) cylinder of 300 litres ("Tank 1") via a heat transfer coil, See figure 1. Once the temperature at the base of the DHW tank reaches 65°C, a three way valve diverts the solar energy to a Seasonal Store tank ("Tank 2") of capacity 23,000 litres.

DHW hot water is drawn from the top of Tank 1, for domestic use, whereas the water in Tank 2 is not drawn and simply performs the task of providing a thermal store. Due to the design employed, thermal stratification does not occur to any great extent in Tank 2, with the temperature difference between the top and bottom of the tank rarely exceeding 2°C. The water in Tank 2 does not change and is used purely as an indirect sensible heat store. Tank 2 supplies heat via a coil to the underfloor heating system and the Heat Recovery and Ventilation (HRV) system and also provides a preheat to the DHW feed. This arrangement ensures

1. The solar fraction for DHW is exceptionally high

2. Heat surplus to the DHW need is stored for winter use, ensuring the space heating Solar Fraction is increased.

The cycle commences in February with the lowest tank temperature and finishes the following February once the design summer temperature of 85°C has been attained and utilized over December and January.

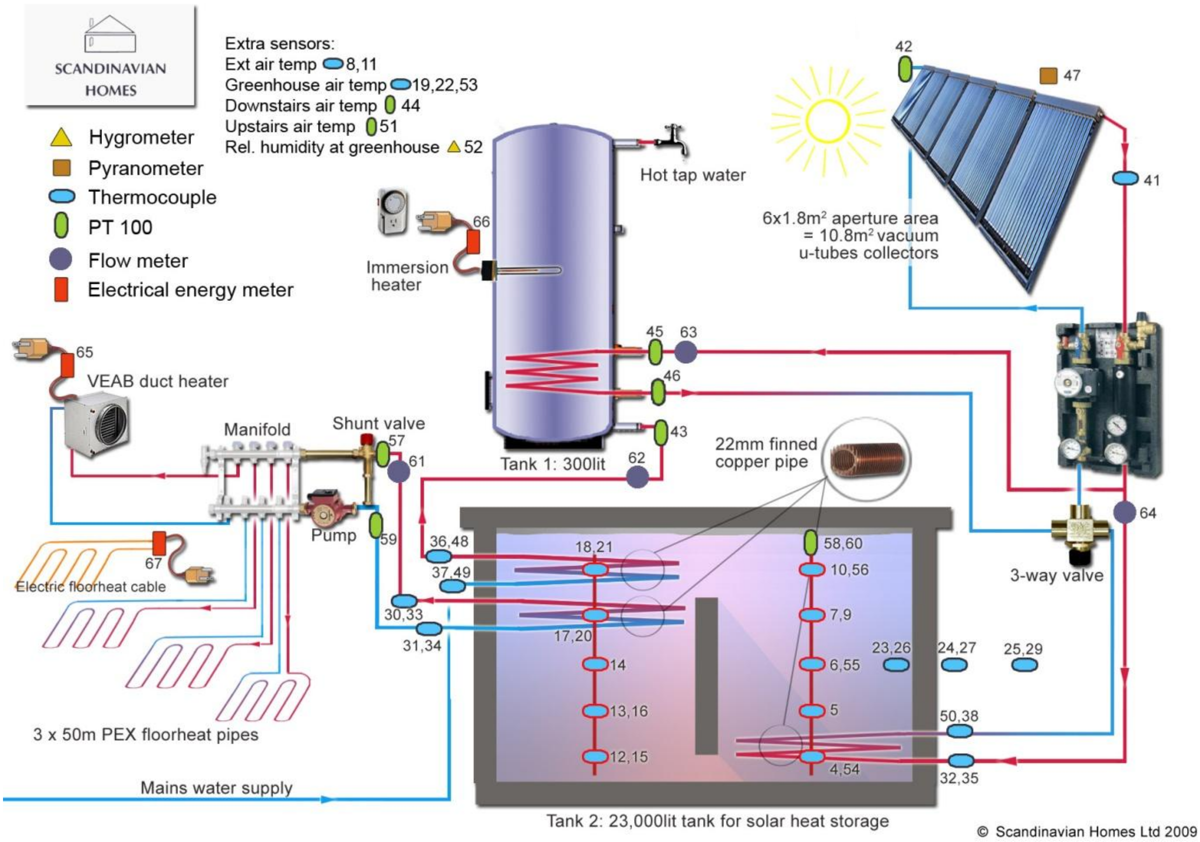

Fig 1. – Diagram of Seasonal Store Infrastructure

2. Methodology

In order to determine the potential for solar assisted space heating, the pattern of space heating demand was investigated for the Passive House under study using the Passive House Planning Package (PHPP). The monthly space heating demand (expressed in kWh) was obtained directly from the PHPP "Monthly Method" worksheet.

The Solar Fraction of the space heating demand calculated using the PHPP climate data. The monthly Solar Energy available per m^2 on the tilted collector surface was obtained from the "SolarDHW" worksheet. This figure was multiplied within PHPP by a conversion factor for Evacuated Tube Solar Collectors, the product of which was then multiplied by a collector area of 6m^2 to give the available space heating supply. Using the monthly figures obtained as described above, the monthly solar fraction was calculated and the figures for total annual space heating demand and total annual solar energy available (i.e. the yield of 6m^2 of panels) were also found.

3. Results

3.1 Passive House Planning Package Space Heating Results

The key performance criteria above were obtained using PHPP climate data for a number of European locations. Tables 1 and 2 respectively show the monthly data obtained for the temperate maritime climate of Dublin and the continental climate represented by Frankfurt. The annualised results are

Dublin					**Specific Space Heating Demand**	**8.5**	**kWhr/m2/a**				**Frequency of Overheating**	**0**		
				Months requiring heating	**10**								**No. of mths where solar contributes >10% of space htg reqt**	**10**
		Months requiring >10kWhr htg			**8**									
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Heat Reqts {kWh}		425	366	213	65	13	1	0	0	1	35	276	436	1832
Incident Solar {kWh/m2}		38	50	96	135	161	151	162	133	109	73	41	26	1174
Net Solar Available {kWh}		79	104	200	281	334	314	337	277	226	152	84	55	2444
Surplus/deficit {kWh}		-346	-262	-13	215	321	313	337	276	225	117	-191	-381	612
% of Dmd met		19	28	94	429	2591	22564	0	0	16950	439	31	13	133

Table 1 - Heating Demand and solar contribution per month for Dublin

Frankfurt					**Specific Space Heating Demand**	**16**	**kWhr/m2/a**				**Frequency of Overheating**	**0**		
				Months requiring heating	**8**								**No. of mths where solar contributes >10% of space htg reqt**	**5**
				Months requiring >10kWhr htg	**7**									
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Heat Reqts {kWh}		943	594	356	53	2	0	0	0	0	76	513	890	3426
Incident Solar {kWh/m2}		34	65	96	133	155	145	162	150	120	77	43	25	1206
Net Solar Available {kWh}		72	134	200	277	323	302	338	313	249	161	89	52	2511
Surplus/deficit {kWh}		-871	-459	-156	224	321	302	338	313	249	85	-424	-838	-915
% of Dmd met		8	23	56	524	0	0	0	0	0	212	17	6	73

Table 2 - Heating Demand and solar contribution per month for Frankfurt

Location	Specific Space Heating Demand {kWhr/m2/a}	Number of Months requiring Space Heating	Number of months requiring >10kWhrs space heating	Number of Months with Solar Fraction >10%	Surplus (+) / Deficit (-) of Solar Energy for Space Heating {kWhr}	Space Heating Demand met by Solar {%} – Annual Solar Fraction
Dublin, Ireland	8.5	10	8	10	612	133
Birr, Ireland	11.5	11	8	11	-139	94
London, UK	11.6	8	7	6	-146	94
Manchester, UK	12.6	9	7	8	-284	89
Glasgow	15.3	11	8	9	-1040	68
Paris, France	10.8	8	7	8	285	112
Marseille, France	1.2	6	3	6	3607	1507
Frankfurt, Germany	16.0	8	7	5	-915	73
Freiburg, Germany	12.3	8	7	8	37	101
Vienna, Austria	13.3	7	7	6	-91	97
Copenhagen, Denmark	18.1	9	7	7	-1293	67
Barcelona, Spain	0.4	5	3	5	3384	3875
Rome, Italy	0.4	5	3	5	3793	4210
Amsterdam, Netherlands	12.0	9	7	6	-28	99

Table 3 – Space Heating requirements and solar fractions for European locations

summarised in Table 3. For the purposes of analysis, it was assumed a seasonal store with a theoretical loss of 0 is available.

The months where even a small heating load existed were included in the above analysis in recognition of the very low energy consumption of the Passive House under study.

As can be seen from Table 3, the design of the house construction under study, meets the PHI requirement of <15kWh/m^2/a in almost all cases, and is thus deemed an appropriate design from which to draw conclusions.

The following results are of note.

- Both Irish locations for which climate data is available in the PHPP are seen to have high number of instances of months that require heating.
- The total annual heating demand is low in Ireland reflecting the temperate maritime climate.
- Ireland has the largest number of months with a solar fraction greater than 10%
- Due to its temperate climate, 18% of the space heating demand is met by solar during January in Dublin, versus for example only 8% in Frankfurt.
- This pattern is matched most closely by Glasgow. However, in the case of Glasgow the annual heating demand is higher, resulting in a yearly solar fraction of only 68%.
- The southerly cities of Marseille, Barcelona and Rome benefit from a mild climate and do not have a significant heating demand and only have 3 months where the heating demand is over 10kWhrs. The cities with a central continental climate (Frankfurt, Vienna, Freiburg) have higher annual heating demand, but also have good annual solar fractions.

3.2 Results from measurements at installation

3.2.1 Tank Losses

Figure 2 shows the mean bulk tank temperature of the seasonal storage tank from the start of October to the end of May. It can be seen that the tank lost 6°C (net) of temperature from its peak temperature of 46°C on the 20th of October to the time when the tank started to supply the space heating system of the house on the 25th of November.

Tanks losses form a significant factor in the performance of the Seasonal Energy Store, as can be seen from the forecast figures shown in Table 4 below. This is despite the exceptionally high levels of insulation employed in the installation (in excess of 600mm EPS). The total forecast losses amount to 3697kWh, approximately double the forecast heating requirement.

The daily heat loss from the tank was calculated using a cool down test. The calculations were based on the ambient soil temperature at the tank wall and the water temperature in the seasonal store. Two periods exceeding 4 days duration were examined where no solar heat was input to the Seasonal Store due to poor incident radiation. In order to calculate the heat loss coefficient for the tank, the following equation (Eq 1) was used (ISO9459-2, 1995)

$$U_s{}^* = \frac{\rho_w c_{pw} V_s}{\Delta t} \ln\left[\frac{t_i - t_{as(av)}}{t_f - t_{as(av)}}\right] \qquad (1)$$

ρ_w {kg/m^3} is the water density at the specific temperature
c_{pw} {J/kgK} is the specific heat capacity of water at the specific temperature
V_s {m^3} is the Volume of water in the tank
Δt {s} is the period of averaging

t_i {°C} is the water temperature at the start of the assessment period
t_f {°C} is the water temperature at the start of the assessment period
$t_{as(av)}$ is the average ambient soil temperature over the period of assessment

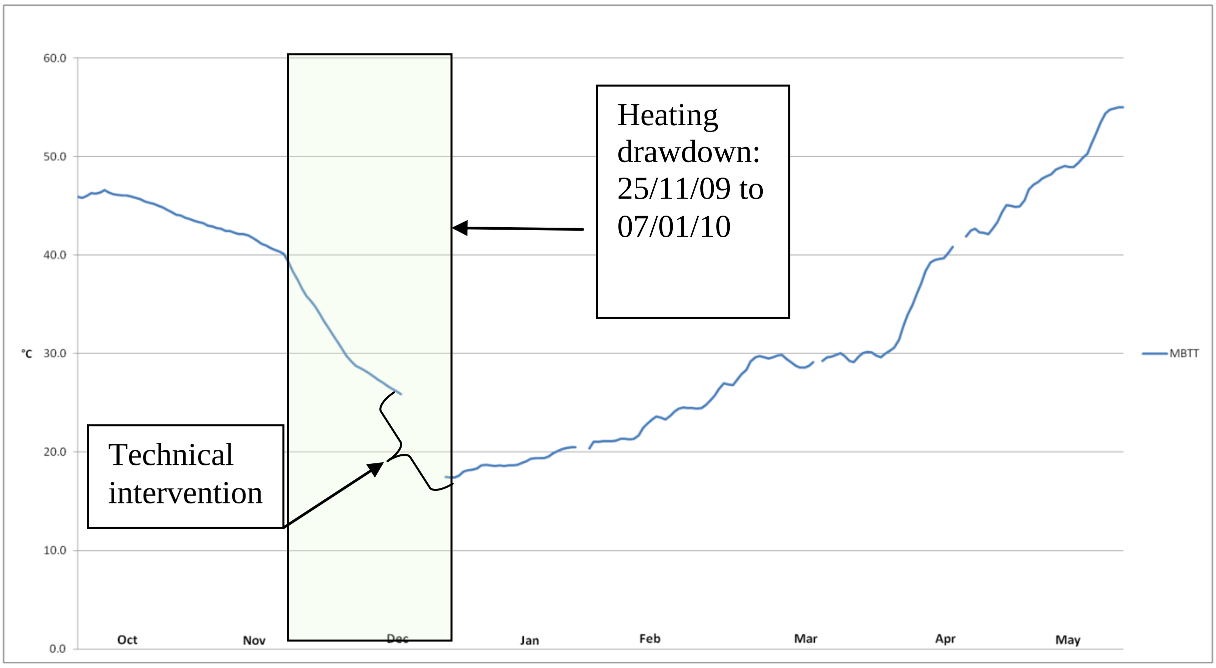

Fig 2 - Overview of Seasonal Energy Store Temperatures for eight month period

From the figures obtained from two cool down tests, Eq 1 yields a result of 10 W/K for the heat loss co-efficient. Using Eq 2 below the forecast tank loss was calculated and is presented in table 4.

$$\text{Tank Loss} = \Delta t * U_z * 24 / 1000 \text{ \{kWh\}}, \qquad (2)$$

Month	**jan**	**feb**	**mar**	**apr**	**may**	**jun**	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**
Ave MBTT {°C}	40	20	30	40	55	65	75	85	85	80	70	50
Soil Temp {°C}	6.5	8	9	12	14	17	19	21	21	20	19	15
Tank Losses {kwh}	241	86	151	202	295	346	403	461	461	432	367	252
Potential Daily Temp Loss {°C}	0.3	0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.5	0.5	0.3

Table 4 – Forecast Seasonal Energy Store tank temperatures and losses per month

3.2.2 Space Heating drawdown from Seasonal Store

Figure 3 below shows daily drawdown of heat from the Seasonal Store for the 25 day period commencing on 25th November 2009. The results are based on recorded daily Mean Bulk Tank Temperatures (MBTT) and recorded heat delivered.

3.3 Solar Fraction

The results for solar fraction are inconclusive given that the analysis was carried out over an incomplete yearly cycle. The results indicate that the solar fraction is 100% for the duration of drawdown from the seasonal store, while the solar fraction is 0% once the tank is depleted. The current configuration of the system is such that all solar energy is directed to the seasonal store once the domestic hot water system is fully charged. Greater use of the solar resource can be made by using solar heat directly in the underfloor and HRV heating system e.g. Table 1 shows a solar fraction in February of 28% could be achieved rather than the attained solar fraction of 0%.

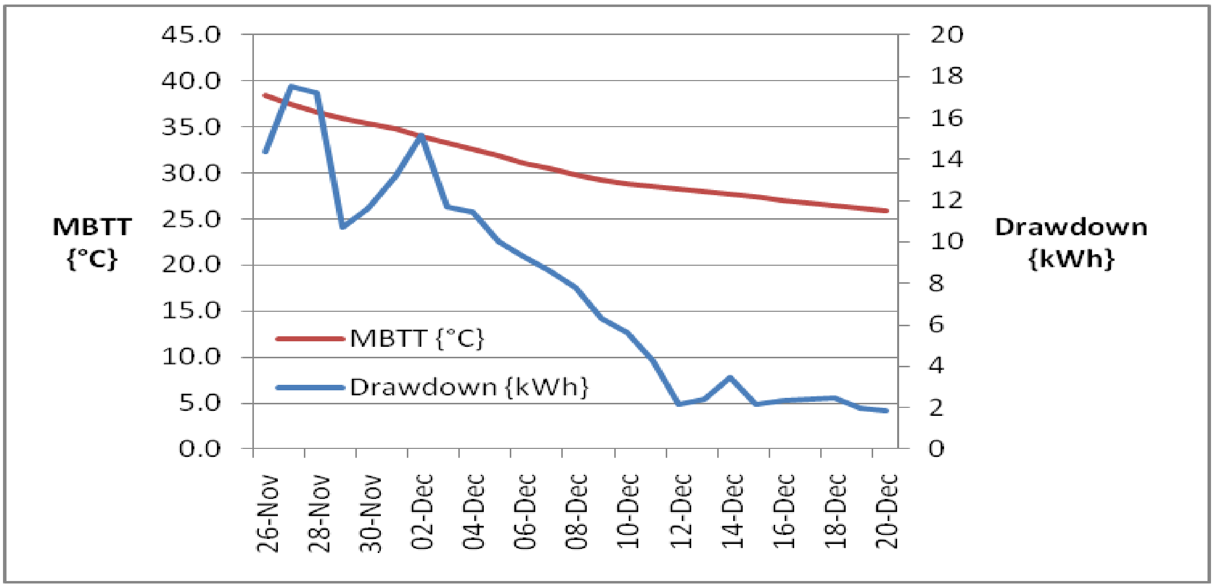

Fig 3 - Mean Bulk Tank Temperatures (MBTT) and corresponding space heating contribution

3.4 Costs

Costs for the installation amounted to €20,168 (parts) and €16,793 (labour), giving a total of €36,961 inclusive of all site costs, a greenhouse built over the Seasonal Energy Store and DHW tank and 10.8m^2 of solar collectors. Taking a 20 year amortisation period, and an interest rate of 3% yields an annual monthly cost of €155 for DHW and space heating.

4. Conclusions

The paper shows that Ireland is a good location in which to exploit solar energy for space heating. Further, through the demonstration project, it has been shown that despite the tank attaining only half it's design temperature of 85°C, an aqueous inter-seasonal store is feasible. CSF's include minimising losses from the seasonal store, ensuring a direct feed from solar panels to the space heating system to maximise the Solar Fraction and finally cost containment.

While the PHPP analysis was carried out using a nominal 6m^2 of solar panels, and a perfect Inter Seasonal Store, the actual installation uses 10.8m^2 and has been demonstrated to have a significant heat loss from the store. The CSF of heat loss from the interseasonal store will be monitored closely as the experiment continues.

5. References

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